Cover Page

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Contact Author	Nobuaki Ohmori (author1)
Email	nobuaki@ut.t.u-tokyo.ac.jp
Phone	+81-3-5841-6234
Fax	+81-3-5841-8527

DEVELOPMENT AND APPLICATION OF GIS-BASED SYSTEM FOR SIMULATING ACTIVITY-TRAVEL PATTERNS UNDER SPATIO-TEMPORAL CONSRAINTS

Nobuaki OHMORI
Research Associate
Institute of Environmental Studies,
Graduate School of Frontier Sciences,
The University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo,
113-8656, Japan
Tel: +81-3-5841-6234
Fax: +81-3-5841-8527
E-mail: nobuaki@ut.t.u-tokyo.ac.jp

Noboru HARATA
Professor
Institute of Environmental Studies,
Graduate School of Frontier Sciences,
The University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo,
113-8656, Japan
Tel: +81-3-5841-6233
Fax: +81-3-5841-8527
E-mail: nhara@ut.t.u-tokyo.ac.jp

Katsutoshi OHTA
Professor
Department of Urban Engineering,
Graduate School of Engineering,
The University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo,
113-8656, Japan
Tel: +81-3-5841-6235
Fax: +81-3-5841-8527
E-mail: katsuohta@ut.t.u-tokyo.ac.jp

Abstract: This paper presents the development and application of GIS-based system for simulating activity-travel patterns under spatio-temporal constraints. Input data consist of three components: travel demand (individual characteristics, activity-travel diary with scheduled activities and travel tracking data), transportation supply (railway network) and activity opportunities (locations and opening hours). The system was developed to apply especially to graduate students studying urban transportation planning. Users can simulate changes of the volume of space-time prisms and feasibility of activity-travel patterns after changing variables such as available time budget, distance between fixed activity locations, travel speed, service hours of railway, location of opportunities, duration of target activities and opening hours of opportunities. The system was very useful for students to understand activity-travel behavior in urban space. The system would contribute to evaluation of space-time accessibility measures after introducing various space-time related policy options not only for students but also for practitioners.

Keywords: GIS, activity-travel pattern, space-time prism

1. INTRODUCTION

Understanding mechanism of individual travel behavior in urban space is essential for urban transportation planning and policy. Conventionally, travel is considered as a derived demand from the desire to engage in activities at certain places. Hence, understanding the relationships between travel behavior and daily activities is effective in estimating individual and household responses to policy measures and to changes of environmental constraints. In addition, public policy should provide individuals with a greater set of options to choose from, and it should distribute these options among the population in more equitable ways (Burns, 1979). It is therefore important to evaluate the potential to engaging in activities considering a wide variety of constraints individuals face. From this view, a lot of research has been conducted about feasibility of engaging in activities under spatio-temporal constraints, what is called space-time accessibility (see, e.g., Lenntorp, 1978; Burns, 1979; Kwan, 1998, Miller, 1999). Especially in recent years, methodologies to analyze travel behavior in temporal dimension are necessary for evaluation of the impact of Transportation Demand Management (TDM) policies and Intelligent Transport Systems (ITS) technologies.

On the other hand, Geographic Information System (GIS) is very effective tool for management, analysis and representation of spatial elements of transportation network and individual travel patterns. In recent years, the development of software and the progress of database preparation have contributed to a wide use of GIS in transportation fields (Thill, 2000; Duker and Ton, 2001). GIS has also been used for the study on activity-travel patterns under spatio-temporal constraints (see, e.g., Segawa and Sadahiro, 1995; Kwan, 1998; Miller, 1999). In this context, not only for practitioners concerning transportation planning and policy, but also for students studying travel behavior, the ability of visual representation of travel patterns in GIS is considered very useful for understanding travel behavior and responses to policy options and to changes of environmental constraints.

This paper presents the development and application of GIS-based system for simulating activity-travel patterns under spatio-temporal constraints. The system is developed to apply especially to graduate students studying urban transportation planning. Section 2 reviews previous studies on activity-travel patterns under spatio-temporal constraints. Section 3 describes the development of the system of which the concept is based on the theory of space-time prism and space-time accessibility. Section 4 describes the results of application to graduate students' exercises in a university. Section 5 concludes the study and mentions further improvement of the system and its application fields.

2. ACTIVITY-TRAVEL PATTERNS UNDER SPATIO-TEMPORAL CONSTRAINTS

More than twenty years ago, Household Activity-Travel Simulator (HATS), essentially gaming simulation, was used very successfully in trying to better understand household travel decisions and the constraints within which those decisions are made (Jones et al., 1983). On the HATS game board, spatial components of activity-travel patterns were represented on a map, and temporal components were represented on a timeline, using information on activity diaries of all members of a household. When a policy measure was introduced, household members discussed together considering changes of constraints on the game board, and new activity-travel patterns were simulated in this board. This tool had originally been developed for policy evaluation but had also been applied for practitioners and students to understand the interrelationships between activity and travel behavior (Jones, 1982).

On the other hand, it is very important to specify the choice set of feasible activity-travel patterns more realistically. The space-time prism constraint formalized by Hägerstrand (1970) is a very useful idea for specifying alternative feasible activity-travel patterns in space-time. Burns (1979) developed the concept of accessibility to space-time dimensions (space-time accessibility) introducing the activity duration at opportunities based on space-time prism constraints. Lenntorp (1978) operationalized Hägerstrand's approach by developing PESASP model that calculated the total number of space-time paths given a specific activity program and the urban transport network. CARLA, which was developed at TSU, is a similar model to generate alternative activity patterns of the day based on combinatorial algorithms (Jones et al., 1983). In recent studies, Kwan (1998) and Miller (1999) operationalized space-time accessibility under the space-time prism on a real world network using GIS.

We have developed GIS-based gaming simulation system: SMAP (Simulation Model for Activity Planning), which has been innovative integration of GIS and feasible activity-travel pattern generation model (Ohmori et al., 2001). The activity-travel pattern generation model can enumerate feasible activity-travel patterns under spatio-temporal constraints of individual's scheduled activities and opening hours of activity opportunities. With the introduction of two persons' activity schedule constraints, not only individual travel modes (walk, bicycle, car-driver and public transport) but also car-passenger mode availability restricted by car-driver's schedule constraints are explicitly dealt with in the model. Initial application of SMAP aimed to understand constraints to affect travel behavior of the elderly households and their responses to changes of the constraints in a local city.

3. DEVELOPMENT OF THE SYSTEM

3.1 Theory of Space-Time Prism and Space-Time Accessibility

Accessibility is an important concept in urban transportation planning and policy. In general, only spatial components of accessibility, e.g., distance or travel time between two separate locations, have been emphasized when evaluating accessibility-enhancing policies. However, essentially both spatial and temporal components of accessibility, which represent potential of engaging in activities at opportunities, should be evaluated considering that travel is a derived demand from engaging in activities. This concept is defined as space-time accessibility (Burns, 1979; Kwan, 1998; Miller, 1999). In this context, the concept of space-time prism is a very useful especially for determining individual choice set of alternative activity patterns engaging in discretionary activities under spatio-temporal constraints. The space-time volume of prism is also called as Potential Path Space (PPS), and projecting the PPS onto the planar space provides the potential path area (PPA). The PPS and PPA are determined by three elements: time budget (the amount of available time between two consecutive fixed scheduled activities), velocity of available travel mode and distance between two locations at which fixed activities are engaged in. When an individual uses public transport, the service hours and timetable of public transport could also restrict the prism.

In addition, the individual can generally engage in certain activities only at the opportunities in urban space (except for the case in which travel is the main activity, e.g., jogging, bicycling and leisure travel). The prism delimits, both spatially and temporally, available opportunities within the time budget. Locations and opening hours of opportunities are therefore significant elements affecting space-time accessibility. Another element is activity duration needed for complete implementation of the activity. These elements are criminal variables to determine space-time accessibility. The system developed in this paper aims to simulate the space-time volume of prism and feasibility of engaging in discretionary activities in prisms, which represents space-time accessibility measures, before and after changing the variables mentioned above. Table 1 shows the six variables and possible options for increasing space-time accessibility.

The system presented in this paper is a new version of SMAP and improved for system users to operate by themselves. The users can simulate PPA (available opportunities with the available time) and feasibility of engaging in an activity in prism constraint. A distinctive point is to use not hypothesized but real activity schedule from the users' activity diary data, so that they can conduct simulation in more realistic situations on the basis of their daily activity schedules and urban environment. The concept of space-time prism would be easy to understand, if travel velocity is assumed to be constant across space for analytical simplicity (the shape of PPA is an ellipse and that of PPS is a combination of two cones). However, in real urban space, the shape of PPA is not simple, because it depends on transportation network system. It may be difficult for (under) graduate students to imagine the actual PPA they face in daily life, even if they take a lecture on travel behavior under spatio-temporal

Table 1 The Variables Affecting Space-Time Accessibility and Possible Options for Increasing Space-Time Accessibility

Variables	Options for increasing accessibility
Time budget	● Delete fixed activities or shorten the duration of fixed activities
Distance between two fixed activities	● Relocate base locations (home, work and school, etc.)
Travel velocity	● More rapid travel mode is available ● Increase speed of the available mode
Location of opportunities	● Relocate locations of discretional activity opportunities ● Closer opportunities are available
Opening hours	● Extend opening hours of opportunities
Activity duration	● Increase efficiency of the activity ● Reduce waiting time at the opportunity

constraints to understand the theory of prism. For the above reasons, simulation exercises using their real activity data is considered to be useful to better understand the concept of prism and space-time accessibility.

3.2 Details of the System Developed in the Study

MapInfo GIS software was used for the system platform. MapBasic programming software was used for customizing MapInfo, and system users could operate the system by clicking added menu bars. Since the previous SMAP needed several complicated procedures to operate, an interviewer operated it and respondents answered the questions by looking at a computer screen (Ohmoi et al., 2001). This new system was developed so that system users could operate it themselves. We named this system SMAP-E (SMAP for Education).

Figure 1 shows the structure of SMAP-E. Input data consist of three components: travel demand, transportation supply and activity opportunities. Travel demand side data on individual characteristics (travel mode availability, travel cost budget and the maximum walking time), activity-travel diary with space-time constraints of scheduled activities are necessary for calculation of prisms. Detailed spatio-temporal travel tracking data, collected by positioning technologies (Global Positioning System (GPS) or Personal Handyphone System (PHS)), are used for representing travel routes in GIS.

Data on spatio-temporal components of transportation network and activity opportunities are prepared in GIS. Although available mode is only railway in this study, it is enough for users, who live in Tokyo metropolitan area and travel mainly by walk and railway, to simulate their activity-travel patterns. Line hole and transfer links in the railway network have attributes of their length and the average travel speed. Travel time through the route of the minimum travel time between two stations is calculated using the railway network. Access and egress mode from an opportunity to railway stations is supposed to be walking. Without preparing road network data, access and egress time is calculated from the distance between the opportunity and the railway stations divided by walk speed (4km/h). Since the timetable of each railway route is not considered in the study, service hours are simply set that all routes have the same hours. Opportunity data are locations and opening hours of all opportunities that the system user visited at during the study term.

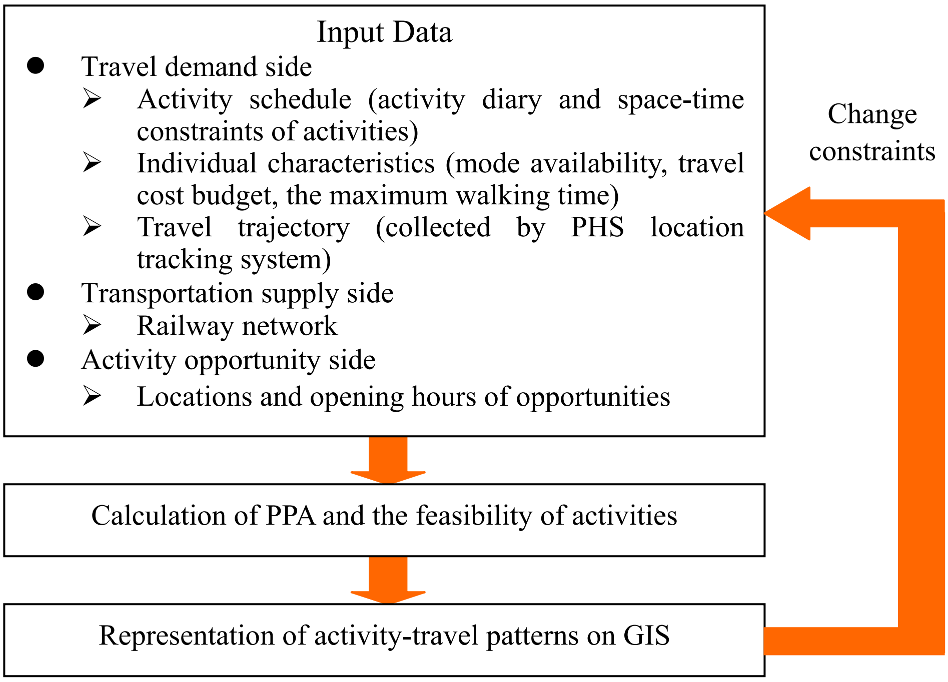

Figure 1 The Structure of SMAP-E

SMAP-E has been designed for the spatial volume of prism (PPA) and the feasibility of engaging in activities in PPA to be simulated and represented virtually on GIS, before and after changes of constraints. The C program that is run from a menu bar on the customized MapInfo implements the module calculating PPA and the feasibility of activity in a prism.

PPA and the feasibility of activity engagement are calculated according to the following advanced space-time prism concept (see Ohmori et al., 1999; Ohmori et al., 2001). Activities are classified into three types: activity (a) is fixed activity, activity (b) is planned but flexible activity and activity (c) is discretionary activity. Components of individual *X*'s activity-travel pattern are defined as:

$TS_{n_X}^X$, $TE_{n_X}^X$: The earliest start time and the latest end time of the n_X-th prism of individual *X*

L_i^X , L_j^X : Locations where the n_X-th prism of individual *X* starts and ends

L_k : Location of opportunity *k*

$\sum AT_{b,n_X}^X$: The sum of the duration of activities (b) in which individual *X* engages between times $TS_{n_X}^X$ and $TE_{n_X}^X$

$t_{m,ij}$: Travel time from location *i* to location *j* by travel mode *m*

T_k : Activity duration that individual *X* engages in the target activity at opportunity *k*

OS_l^k , OE_l^k : The *l*-th start time and end time of opening hours of opportunity *k*

$Trip\_Start\_Time_{n_X}^X$: Travel start time of individual *X* in the n_X-th prism

$TE_{n_X}^X - TS_{n_X}^X - \sum AT_{b,n_X}^X$ is the time budget for engaging in activities (c) and travel for individual *X*. Individual *X* can engage in the target activity at opportunity *k* in the n_X-th prism within the time budget $TE_{n_X}^X - TS_{n_X}^X - \sum AT_{b,n_X}^X$, only when s/he starts traveling after $TS_{n_X}^X$ by travel mode *m*, arrives at location L_k after OS_l^k, engages in the activity for T_k, leaves before OE_l^k by mode *m* and arrives before $TE_{n_X}^X$. If positive number of $Trip\_Start\_Time_{n_X}^X$ exists subject to the following equations (1) through (5), the activity engagement at opportunity *k* in the n_X-th prism is feasible for individual *X*.

$$Trip\_Start\_Time_{n_X}^X \geq TS_{n_X}^X \quad (1)$$

$$Trip\_Start\_Time_{n_X}^X + t_{m,L_i^X L_k} \geq OS_l^k \quad (2)$$

$$Trip\_Start\_Time_{n_X}^X + t_{m,L_i^X L_k} + T_k \leq OE_l^k \quad (3)$$

$$Trip\_Start\_Time_{n_X}^X + t_{m,L_i^X L_k} + T_k + t_{m,L_k L_j^X} \leq TE_{n_X}^X \quad (4)$$

$$TE_{n_X}^X - TS_{n_X}^X - \sum AT_{b,n_X}^X \geq t_{m,L_i^X L_k} + T_k + t_{m,L_k L_j^X} \quad (5)$$

Under this assumption, PPA consists of all the opportunities *k* at which the engagement in the target activity is feasible in a prism.

As shown in Figure 2, transparent sheets had been used and layered in HATS for drawing activity schedule, travel pattern, and transportation network and opportunities (Jones, 1982). Each GIS layer in SMAP-E exactly substitutes this function. Figure 3 shows the concept of GIS data use in SMAP-E on spatio-temporal dimension.

4. APPLICATION TO GRADUATE STUDENTS EXERCISES

4.1 Schedule of the Exercise

SMAP-E had been applied to the exercise "Environmental Information Exercise in Spatial Planning and Policy" for graduate students at the University of Tokyo in 2001 and 2002 years.

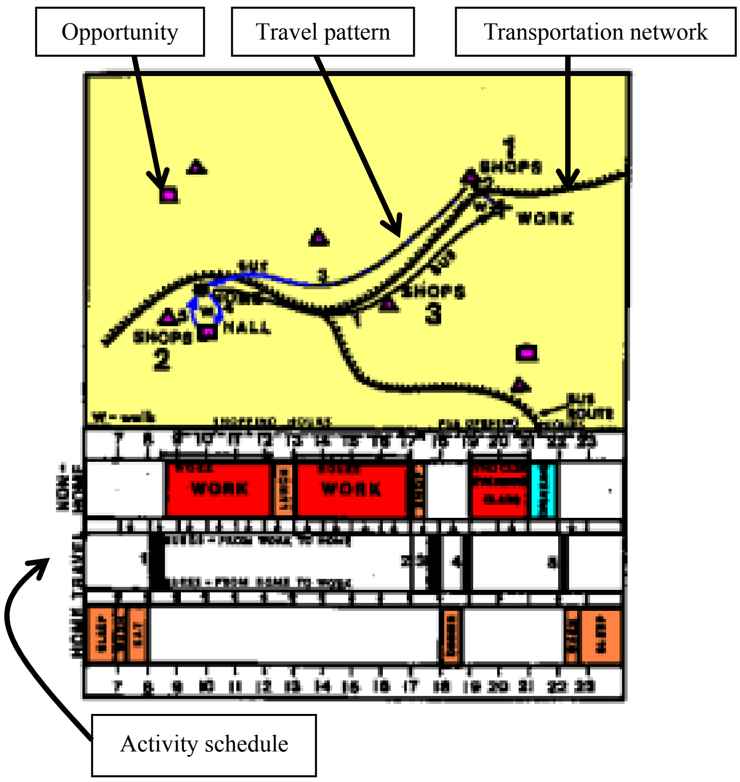

Figure 2 HATS Game Board (Jones, 1982)

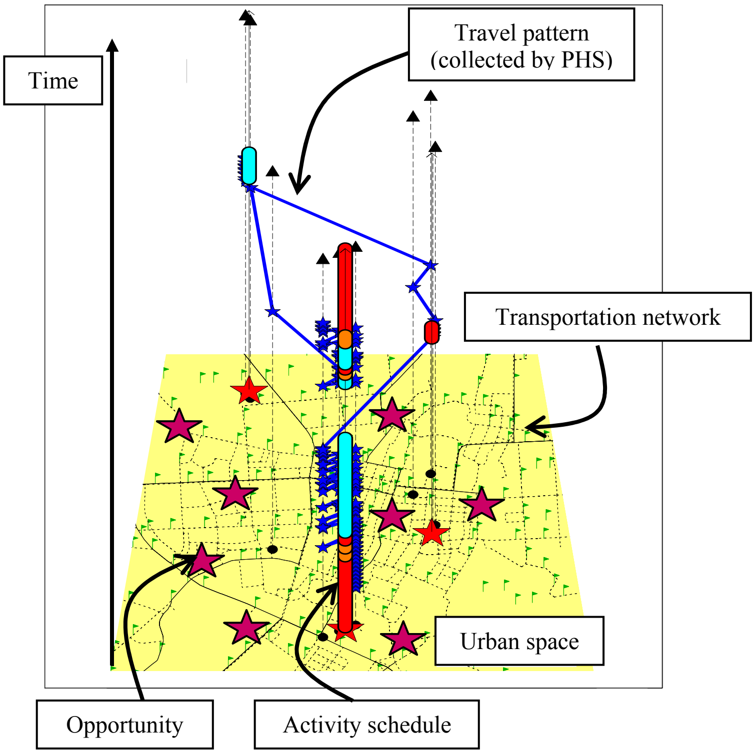

Figure 3 The Concept of GIS Data Use in SMAP-E

The objective of this exercise was to complement the lecture "Environmental Information System in Spatial Planning and Policy" and to better understand interrelationships between environmental information and individual activity patterns. The schedule of the exercise is as follows:

- The 1st week : Collect travel data using GPS and PHS.
- The 2nd week : Record one-week activity-travel diary in a survey sheet, and collect travel tracking data by carrying PHS.
- The 3rd week : Learn how to use MapInfo software, and represent PHS data on MapInfo.
- The 4th week : Input activity-travel diary data in a Excel sheet, and prepare opportunity data on MapInfo.
- The 5th week : Represent and analyze spatial and temporal components of one-week activity-travel pattern.
- The 6th week : Submit the first report titled "My one-week activity-travel patterns."
- The 7th week : Take a lecture on individual activity-travel patterns under spatio-temporal constraints in urban space.
- The 8th week : Take a lecture on transportation network and activity opportunities.
- The 9th week : Learn how to use SMAP-E, and simulate activity-travel patterns.
- The 10th week : Submit the second report titled "Understanding activity-travel patterns using SMAP-E."

Seventeen students participated in the exercise in 2001 year and eleven students in 2002 year. About half of the students had not used any GIS software before the exercise. From the 2nd week to the 3rd week, the students recorded their one-week activity diary in a survey sheet and carried PHS device for the purpose of automatically collecting data on spatio-temporal movement. PEAMON (see Okamoto et al., 2000) was used in the 2001 exercise, and PHS operated by NTT DoCoMo, Inc. was used in the 2002 exercise. Positional data were collected from morning to midnight at a specific time interval during the survey period. In the 2001 exercise, travel-tracking data were collected using off-line PHS system. On the other hand, on-line PHS system was used in the 2002 exercise. The students were sent, by e-mail, several maps showing travel trajectory of that day, after 23:00 every other day. PHS systems used in the two exercises are summarized in Table 2.

Before using SMAP-E, the students were assigned to submit the first report on their one-week activity-travel patterns (see the schedule, 6th week). This report was written on the analysis of only travel demand side data, i.e., activity-travel diary and PHS tracking data. Then, the students had lecture on activity-travel behavior under spatio-temporal constraints (activity schedule, transportation network and activity opportunities in urban area). Having basic knowledge about prism and accessibility, the students conducted the simulation exercise using SMAP-E and submitted the second report on activity-travel patterns under spatio-temporal constraints.

Table 2 PHS Systems Used in the Exercises

	2001 year	2002 year
The number of participants	17	11
PHS system	PEAMON	NTT DoCoMo, Inc.
Data collection	Off-line	On-line
Time Interval	1 minute	5 minutes
Time period	From 8:00 to 22:00	From 7:00 to 23:00

4.2 Simulation Exercise Using SMAP-E

One-week activity diary and PHS spatio-temporal tracking data of all users were stored in the server computer. The users were able to access these data via the intranet. The process of operating SMAP-E is described below. In the beginning, a user starts a MapBasic program on MapInfo. Then, the user selects his identification number and set constraints such as mode availability, travel cost budget and the maximum walking time (in the exercise, available mode was only railway, and travel cost were not introduced, because database of travel fare had not been prepared). Next, he selects a target day from seven days and sets fixed activity scheduling constraints. As shown in Figure 4, time use of the day is represented as in-home, travel and out-of-home at the left side timeline, and travel trajectory (drawn by blue poly-line) of the day is represented on the right side map. Continuously, the C program calculates PPA for all prisms in the day. He can identify a PPA on a map component and simulate the PPA after changing constraints. Actually, railway stations within PPA are displayed and color-coded by the available time at the station (in Figure 4, red indicates 0-30 minutes, yellow 30-60 and green 60-90) as a representative of available opportunities. Furthermore, he can test the feasibility of engaging in a target activity at a specific site (one of his visited opportunities during the survey period) within a prism (as shown in Figure 5).

As mentioned previously, the objective of the exercise was to help students to understand the important elements directly affecting space-time accessibility. The students were assigned to conduct the following simulation exercises ((1) to (8) correspond to Figure 6):

- Compare the volume of prisms (locations and the number of the railway stations in a prism, classified by the available time) at different time of day, and simulate the volume of a prism before and after changing (1) time budget, (2) distance between fixed activity locations, (3) velocity and (4) railway service hours.
- Simulate the feasibility of engaging in a discretionary activity in a prism before and after changing (5) the volume of a prism, (6) activity duration, (7) location of an opportunity and (8) opening hours of the opportunity.

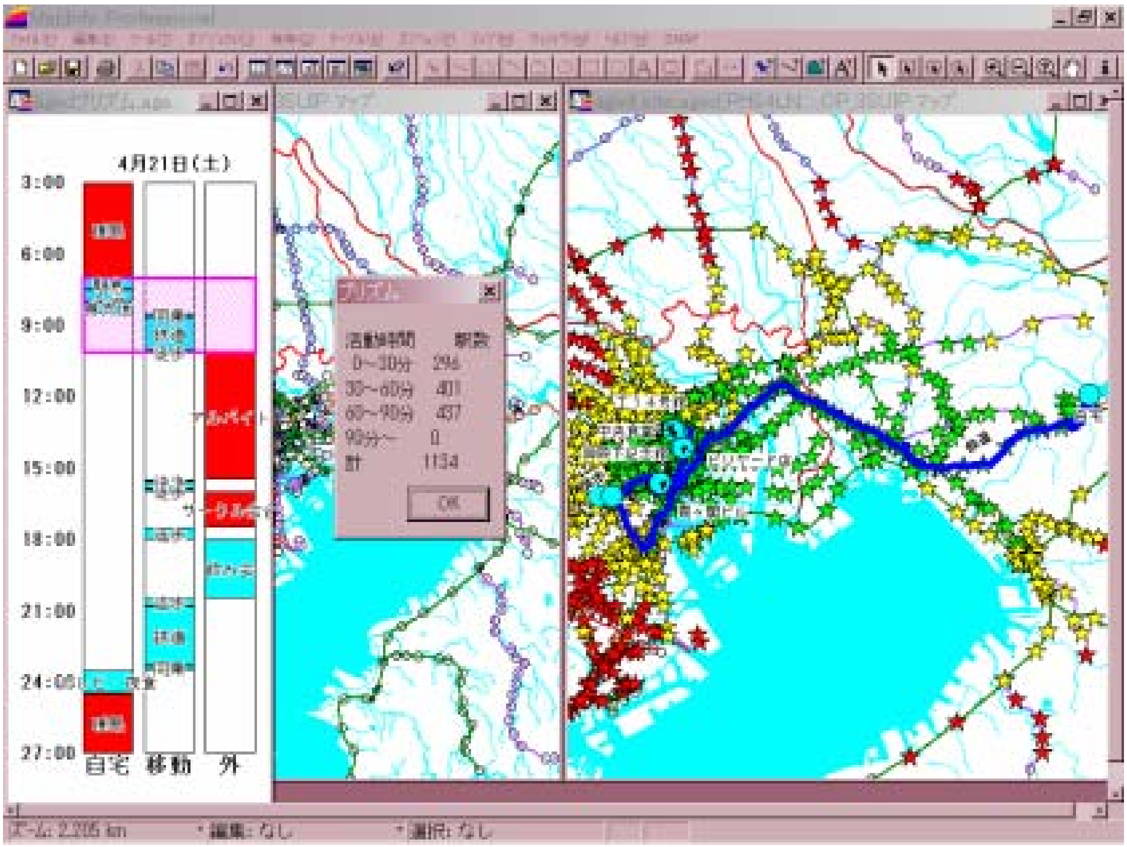

Figure 4 Representation of Activity-Travel Patterns and Available Opportunities within a Space-Time Prism on SMAP-E

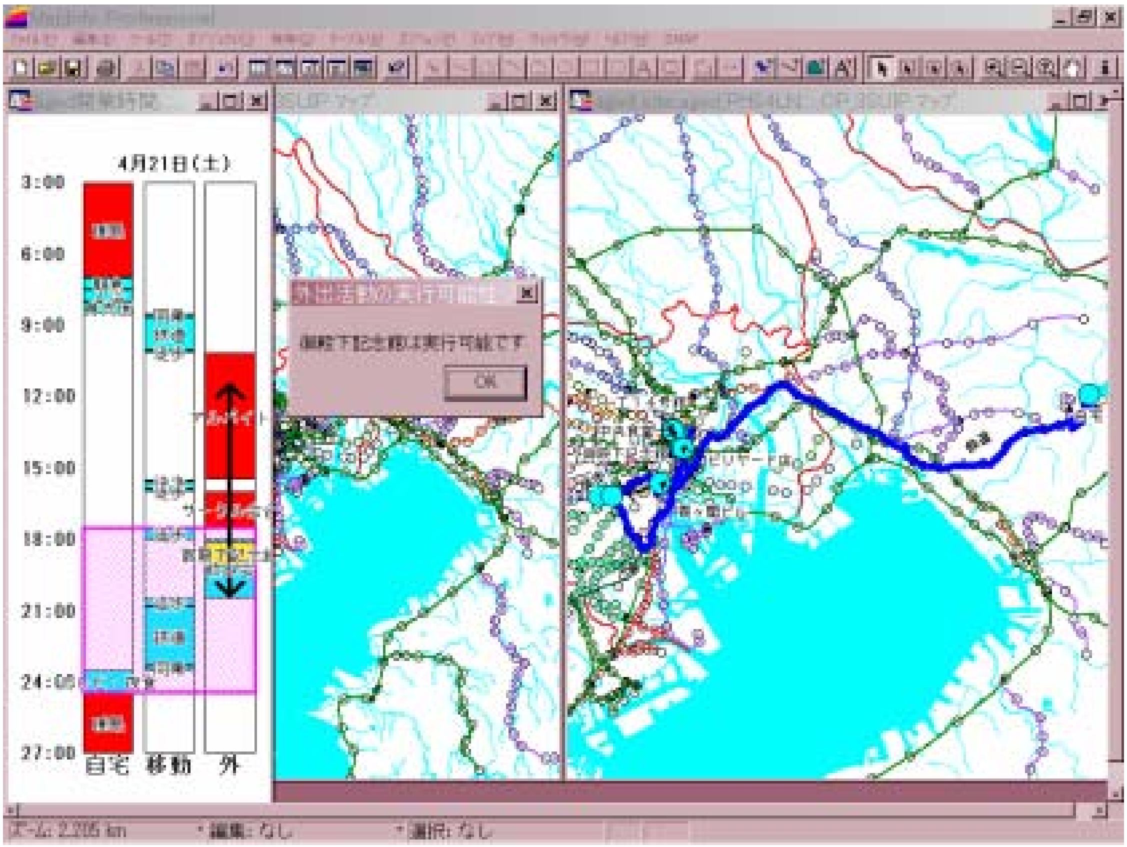

Figure 5 Representation of the Feasibility of Engaging in the Target Activity on SMAP-E

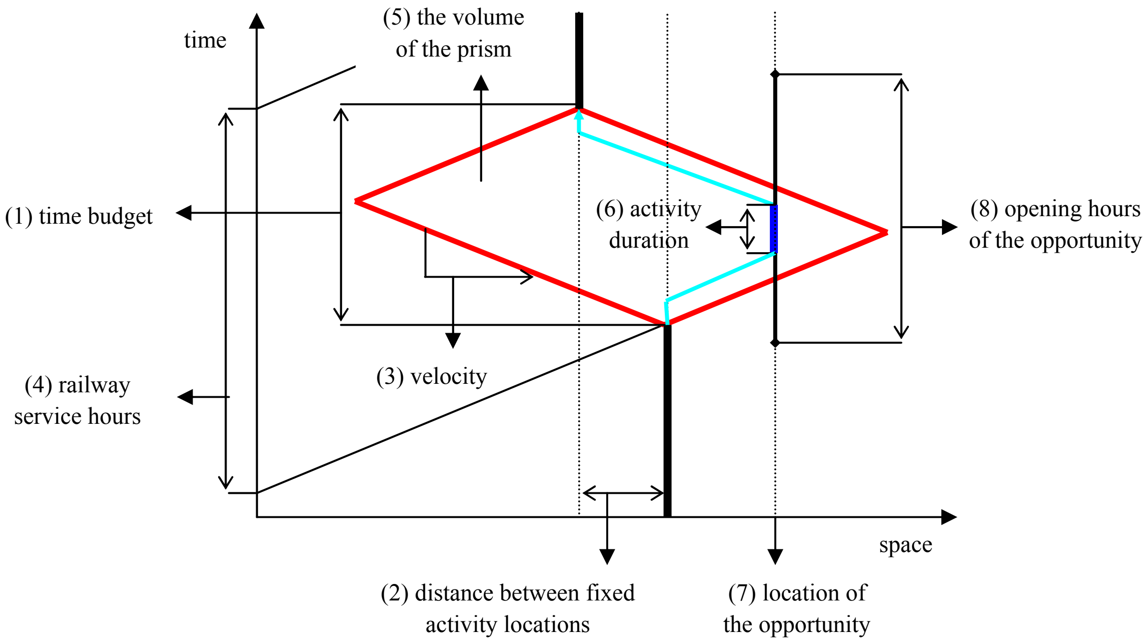

Figure 6 Operational Variables in the Simulation Exercises

Finally, they submitted the second report that consisted of discussion about the simulation results and their opinion about effectiveness and improvement of SMAP-E.

4.3 Analysis of the Students' Reports

From the students' reports, it was found that a series of simulation using SMAP-E had contributed to help students to understand theory of space-time prism and activity-travel patterns under spatio-temporal constraints. In the first report, before the simulation exercises using SMAP-E, there were descriptions about their time use and travel patterns, for example, "Travel time occupied a large amount of a day," "Every day, I sleep very long time," "I found that my time use was not efficient," "My activity-travel patterns varied every other day," "I didn't go to any other places than a university, what a boring life!" "It is the first time to identify the travel routes of my trips." These statements indicate that analysis of their own one-week activity-travel patterns by themselves should be effective for looking back their daily life. In the simulation exercise, on the other hand, the students were able to realize spatio-temporal constraints to their activity-travel patterns by examining not only activity schedule but also transportation network and opportunities. In the second report were a number of descriptions that suggest usefulness of SMAP-E. Some of the interesting comments on the simulation results are described below:

- Moving to nearer the university contributed both to decreasing travel time and increasing the available time for discretionary activities.
- Deleting a short-time fixed activity resulted in combining two consecutive prisms and increasing PPA considerably (see Figure 7).
- Getting up earlier enlarged a prism in the morning but did not contribute increase of the available time at an opportunity. This was because opening hours of the opportunity constrained the available time in the early morning (see Figure 8).
- Compared the difference of activity type depending on the available time at an opportunity. At a bookstore, 150 minutes are enough for me to browse and choose books, but in 18 minutes, I can search for a book only when I have already decided what book to buy. If only 2 minutes are available at the bookstore, I won't be able to buy any books

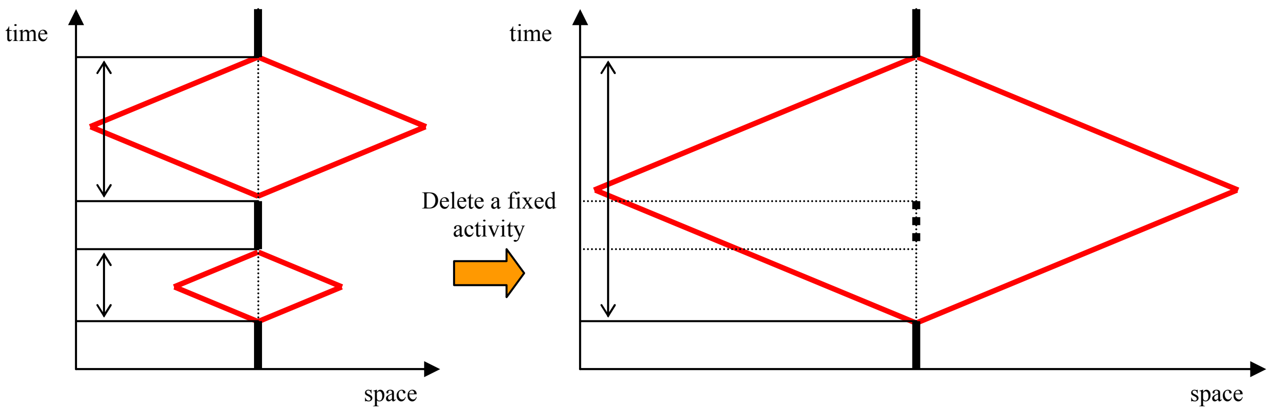

Figure 7 Combining Two Consecutive Prisms by Deleting a Fixed Activity

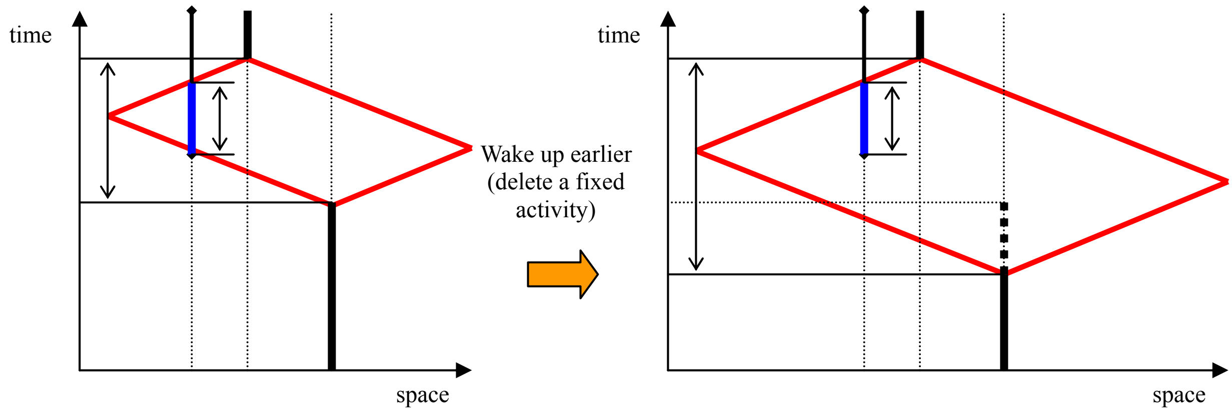

Figure 8 The Unchanged Available Time at an Opportunity after Prism Enlargement

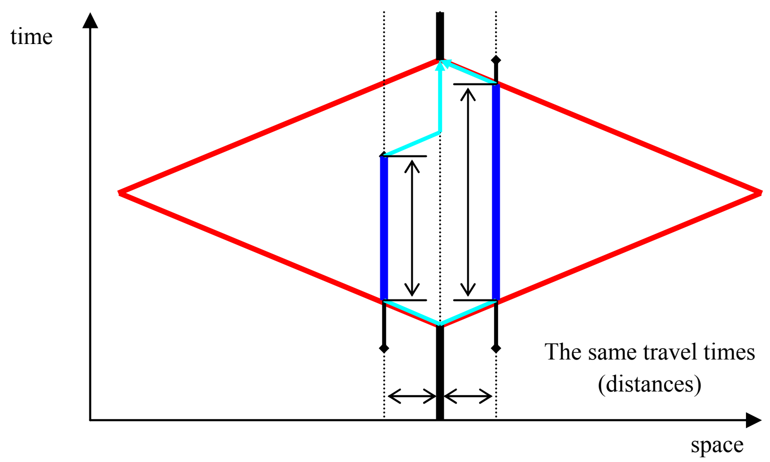

Figure 9 The Difference of the Available Time at Two Locations Reached at in the Same Travel Times

unless I know where they are in the store.

- Realized that I couldn't actually change the locations or opening hours of any opportunities, or railway speed, but the activity schedule could be coordinated, to some extent, by my discretion.
- Examined the feasibility of having a lunch activity at two restaurants that located at different places but were reached at in the same travel times, when I wondered why the available times differ in two. Just before submitting this report, I became aware that

opening hours of one restaurant limited the available time in a prism (see Figure 9).

SMAP-E was found to be the very effective system for simulating activity-travel patterns after changing major elements affecting space-time accessibility. However, further improvement in the system could enable users more realistic and practical simulation. From the analysis of the students' reports, the following improvements are considered to be useful in future:

- Introduce travel modes such as walk, bicycle, car driver and bus, in addition to railway.
  - It is important to provide individuals multi-modal alternatives in transportation policy. Preparing and introducing road and bus network data would contribute more realistic calculation of travel times by multi-mode.
- Consider the difference of travel time across the day and week.
  - As for the railway, this is possible by preparing timetable database or integrating public transport information software (for example, "Ekispert" by Val Laboratory Corporation and "Norikae Annai" by Jourdan Co. Ltd.) with SMAP-E. Although it is difficult to explicitly deal with travel time variability on road network, at least the difference between peak and off-peak periods, and weekdays and weekends should be considered.
- Prepare data on activity opportunities other than those visited during the survey period.
  - It is also important to provide individuals alternatives of opportunities in spatial policy. Preparing database about various activity opportunities would be useful for users to find new alternative opportunities and activity patterns.
- Indicate the available time at the opportunity.
  - In the present system, the available time at each station is represented as different colors classified into four or five categories, and the judgment of the feasibility of activity engagement is just "yes" or "no." There were several students who tried to change activity duration step by step and identify the available time. Giving information on the exact available time at opportunities would be very effective and this function could be easily added to the system.
- Set up fixed activity schedules more flexible.
  - Start and end times of prisms are determined by classifying each recorded activity into three types (see section 3.2). Thus, as shown in Figures 7 and 8, increase of time budget can be represented only by deletion of a fixed activity. Improvement of this point could enable users to conduct more useful simulation, for example, "What time should I get up to attend the early morning class in time?"

5. CONCLUSION

This paper presents the development of SMAP-E that is a GIS-based system for simulating space-time prisms and the feasibility of engaging in activities in prisms using activity diary, railway network and opportunity data in Tokyo Metropolitan area. SMAP-E was applied to the exercises for graduate students majoring spatial planning and policy. The students recorded their own one-week activity diaries and simulated PPA and the feasibility of activities in prisms before and after changing important variables affecting space-time accessibility. It was found that the exercises using SMAP-E was very useful for the students to better understand activity-travel behavior under spatio-temporal constraints. However, there is still room for improvement of SMAP-E in order to conduct more realistic and practical simulation. This improvement concerns preparation of database on network and opportunities, and advanced techniques of programming.

In future, the GIS-based system that can simulate individual activity-travel patterns would contribute to evaluation of space-time accessibility measures after introducing various space-time related policy options, such as congestion pricing and flexible working hours. Since the change of travel cost by introduction of congestion pricing at peak periods affects travel behavior, it would be effective for system users to investigate alternative activity-travel patterns (alternative routes, departure times, destinations and modes) with information on travel cost. In case of flexible working hours, because timing of work activity engagiment depends on worker's discretion, not only the volume and timing of prisms but space-time accessibility can be changed. It would be meaningful to investigate the feasibility of engaging in discretionary activities at different working hours, when making decision about departure time to commute. Furthermore, the system would have much advantage for tourists and bussiness travelers when planning activity schedue. Travel tracking data collected by GPS could be also used for representation of detailed travel routes and speed profiles, and for estimation of vehicle emissions.

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REFERENCES

Burns, L.D. (1979) **Transportation, temporal, and spatial components of accessibility**. LexingtonBooks, Lexington.

Duker, K. and Ton, T. (2001) GIS for transportation, In D.A. Hensher and K.J. Button (eds.), **Handbook of Transport Modeling**. Elsevier, Oxford.

Hägerstrand, T. (1970) What about people in regional science?, **Papers of the Regional Science Association**, Vol.24, 7-21.

Jones, P.M. (1982) 'HATS' educational manual: Studying travel in the context of household activity patterns. Transport Studies Unit, Oxford University, Ref.193/PR.

Jones, P.M., Dix, M.C., Clarke, M.I. and Heggie, I.G. (1983) **Understanding travel behavior**. Gower, Aldershot.

Kwan, M.-P. (1998) Space-time and integral measures of individual accessibility: A comparative analysis using a point-based framework, **Geographical Analysis, Vol.30, No.3**, 191-216.

Lenntorp, B. (1978) A time-geographic simulation model of individual activity programmes. In T. Carlstein, D. Parks and N. Thrift (eds.), **Timing Space and Spacing Time 2, Human Activity and Time Geography**. Arnold, London.

Miller, H.J. (1999) Measuring space-time accessibility benefits within transportation networks: Basic theory and computational procedures, **Geographical Analysis, Vol.31, No.2**, 187-212.

Ohmori, N., Muromachi, Y., Harata, N. and Ohta, K. (1999) A study on accessibility and going-out behavior of aged people considering daily activity pattern, **Journal of the Eastern Asia Society for Transportation Studies, Vol.3, No.5**, 139-153.

Ohmori, N., Muromachi, Y., Harata, N. and Ohta, K. (2001) Simulation model for activity planning (SMAP): GIS-based gaming simulation, **Proceedings of the 9th World Conference on Transport Research**, Soul, July 2001.

Okamoto, A., Suzuki, A., Lee, Y.H., Tanabe, J. and Asakura, Y. (2000) Development and Functional Experiment of PEAMON (Personal Activity MONitor), **Proceedings of Infrastructure Planning, Vol.23**, 659-662. (in Japanese)

Segawa, S. and Sadahiro, Y. (1995) A Policy Making Support System for Child Care Facilities using GIS, **Papers and Proceedings of the Geographic Information Systems Association, Vol.4**, 59-64 (in Japanese).

Thill, J. (2000) Geographic information sysems for transportation in perspective, **Transportation Research C, Vol.8**, 3-12.